Fermi National Accelerator Laboratory

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Calibration Beams at the SSC

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Introduction and Basic Assumptions

Experience with the hadron colliders at Fermilab and CERN and the electron-positron collider LEP have indicated that the calibration beam needs at the SSC laboratory will be substantial. We anticipate that the SSC Laboratory will have to have at least one calibration beam per experiment for a period starting six years before and for several years following the commissioning of experiments.[1]

By the time that the beams can be operating at the SSC Laboratory the initial round of experiments will be past the prototype and development stage of calorimeter construction. We anticipate that the primary need will be for system verification and calibration. This stage of operation requires high quality beams and facilities to achieve the performance levels discussed in the various SSC workshops and summer studies that have dealt with SSC detectors.

The source of protons for the test and calibration beams will be the High Energy Booster (HEB), and the Medium Energy Booster (MEB). The energy of the HEB is 2 TeV and, except for the energy, the performance levels are similar to the Tevatron at Fermilab. The total beam from the HEB is assumed to be 2×10^{19} protons per year with a slow extraction of 10^{12} protons per second. This extracted beam can be divided among external beams and delivered to halls set up for the calibration of detectors. The design assumes that there will be a final configuration of 6 halls on the surface and that the beam is brought from the HEB to the surface before splitting and secondary targeting take place. A normal cycle of the HEB, including a 30 second flat-top, is 2.5 minutes. [2]

Beam from the MEB will be used to produce low energy beams in the Calibration Hall. The MEB may cycle as often as every three seconds and have a one second flat-top. Beam from the MEB will be injected into the Switchyard at a point approximately 8000 feet downstream from the HEB injection point. From this point, the 200 GeV beam will be transported to the targets by the Switchyard in the same channels used for the High Energy Beam.

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[1] J.W. Cooper, *Test Beam Requirements at the SSC*, Proceedings of the 1984 Summer study on the Design and Utilization of the Superconducting Super Collider; Snowmass, Colorado, 1984; Rene Donaldson and J. G. Morfin, editors.

[2] Dave Johnson, private communication.

Beam Specifications at Calibration Halls

Two important issues to be addressed in calibration beams are lepton identification (both electron and muon), and jet energy measurement and resolution. For leptons one wishes to study the full energy range with particular emphasis on the high energy end. Jets are, for the most part, a collection of low energy hadrons (1 to 50 GeV); thus, careful measurement of calorimeter response at low energies is important. Because some jets have leading particles and in order to study the probability of a pion giving a muon signature, pion beams should be available over the full energy range. To provide the required dynamic range in beam energy, facilities that can target 200 GeV from the MEB, as well as the 2 TeV beam from the HEB, will be needed.

To study lepton identification the beams should transport the highest possible energy, with fluxes of 100 to 1000 Hertz for each particle type (electron, muon, and pion) at that energy. The minimum flux at which useful data could be taken is about 1 Hertz. In addition, some experimenters may desire primary protons, so that magnets should be able to transport particles up to the full energy of the HEB. The beam momentum bite can be quite broad as long as the particle momenta are individually identified. For hadrons most studies will need fluxes similar to those given above for the lepton studies, except when studying issues of pileup. For this fluxes of 10^7 per pulse will be needed, at energies of about 100 GeV. For a 100 GeV electron beam with a flux of $10^7/cm^2/sec$, an electromagnetic calorimeter will receive a dose at shower maximum of 10^3 rad/sec or a Mrad in 1000 seconds of exposure.[3]

A typical resolution for sampling an electromagnetic calorimeter is expected to be $(15\%/\sqrt{E}+ < 1\%)$, while $(3\%/\sqrt{E})^4$ is the expected resolution for the most optimistic continuous calorimeter. Thus absolute momenta (given by $\int B \times dl$ of the tagging magnet) should be known to better than 0.3% and relative momenta (given by the tagging system) should be known to better than 0.05%. Since the e/π separation in the calorimeters is expected to be in the 100 to 1000 range, the beam particle types should be

[3] SSC-SR-1003 Radiation Levels in the SSC Interaction Regions. D. E. Groom, Editor. Appendix 7, page 128.

[4] M. Chen et al, *The Zenon Olive Detector: A Fast and Precise Calorimeter with High Granularity for the SSC*, Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider; Berkeley, California, 1987; Rene Donaldson and M.G.D. Gilchriese, editors, pg 574

identified to better than 1000:1. In particular, the misidentification of pions as electrons should be below this level. This implies that particle rejection equal to 1000, divided by the fraction of the desired particle in the beam, will be required.

For muons one studies how often pions look like muons, either by not interacting or via hadronic shower punch through giving a muon signature. Here again the misidentification of pions as muons should be below 1000:1. True muons can be identified by survival in or beyond the beam dump, or with a TRD at energies above 500 GeV.

Hadronic studies require mass identification of pions, kaons, or protons and must span the range 1 to 100 GeV with misidentification less than a few percent.

During calorimeter calibration there should be no muons in the calorimeter in the measurement time window. This can be achieved by using a veto counter to reject any muons entering the calorimeter during two integration times of the calorimeter before, and one integration time after, the beam particle passes through the calorimeter. If during low flux operation of the beams the muon fluxes are less than 150 kHz/m^2 then this procedure will not incur any substantial dead time, even for liquid ionization calorimeters.

These requirements are summarized in Table 1.

HEB Options with tunnels to surface

For the purposes of this report we have assumed that the HEB is 20 feet above the collider ring, and that the calibration facilities are at a depth of 35 feet below the surface. However, the vertical profile of the SSC has not been fixed at the time of writing this report. An elevation of 530 feet was taken as the best value at this time. The extracted beams start at the injection line from the HEB to the collider, and are brought to the surface before they are split and secondary beams formed. The beam from the HEB is pitched up at 14.1 mrad by a dipole bend string that runs at 4 Tesla. After 7800 feet of transport the beam reaches the surface, where it is leveled off to a pitch of 9.7 mrad. At this inclination, the beam approximately follows along the surface at about 35 feet below grade. The injection from the MEB begins immediately after this bend. After the MEB injection point, the the first splitting station begins in the Switchyard. Plan and elevation views of this beamline are shown in figures 1 and 2.

Switchyard; Six Beams with High and Low Power Options

The function of the Switchyard is to accept the extracted beam from the HEB and MEB and transmit it to any of six targets with a full range of splitting ratios. The basic units to accomplish the splits are electrostatic septa with a maximum field of 55 KV/cm, and Lambertson splitting magnets for both two way and three way splits. A split is accomplished by causing the beam to intercept the wires of an electrostatic septum, which separates the beam into two beams that are about one inch apart after a drift of about seven hundred feet. This is sufficient separation for the beams to fit into the acceptance of a two-way Lambertson magnet. The split ratio is adjusted by physically moving the electrostatic septum through the beam: the split ratio is determined by the relative amount of beam that lies to either side of the wires.

For a three way split, the beam must be separated into three beams. This is done with two sets of electrostatic septa. The first septum splits the beam into two; the second septum splits one of these into two again, thus making three beams in total. After about a nine hundred foot drift, the three beams will have sufficient separation to fit into the acceptance of a three way Lambertson magnet. For a three-way split, the splitting ratios are adjusted by moving the electrostatic septa wires through the beam just as is done in the two-way split.

The geometry chosen for this study splits the beam into six separate beams, one for each detector station in the calibration beam hall. The easiest way to achieve this is to first let the beam pass through a two-way split to form two beams, and then to allow each of these to go through a three-way split. To modify this geometry for four detector stations rather than six, the three way splits are simply replaced by two-ways, or one of the three-way splits is not initially installed.

Another major unit in the switchyard is the bend string. The splits are accomplished by the electrostatic septa and the Lambertsons, but the separation between the beams can only be achieved with large dipole magnets. For this study, two alternate approaches were used: Namely, a comparison was made between the use of conventional dipoles, and cryogenic dipoles. The length of the bend string (180 feet) is arbitrary, and represents a choice between power and real estate requirements of the Switchyard. If the bend strings are longer, they would use more power, but the Switchyard footprint would be smaller. The strength of the bend strings also depends on whether they are conventional or cryogenic. With cryogenic magnets operating at 4 Tesla, such a string will bend the beam through 30 mrad. Conventional magnets will have about half the field strength, and will therefore only bend the beam through 15 mrad. One can always choose to use a conventional string of bends that is twice as long as a corresponding cryogenic string, to achieve 30 mrad, and then a 360 foot long string would be required. A comparison of conventional and cryogenic Switchyard footprints is shown in figure 3, for a two TeV beam.

The development of the footprint for the external beams can now be understood with the use of these basic elements: electrostatic septa, Lambertson magnets, and dipole bending magnets. The constraints that must be met for the footprint are threefold: The test stations must be separated by 75 feet, (as described in the section on Radiation Shielding) and the target stations must be separated by 30 feet, so that each target pile can operate independently of the others. Furthermore, muon shielding requirements for the test stations mandate that the distance between target and test area be 1640 feet. These parameters fix the size of the footprint, as shown in figure 4. Four major bend strings, each of 30 mrad, will separate the test stations by 75 feet, separate the target stations by 30 feet, and place the test stations 1640 feet downstream of the target stations, in a longitudinal distance of 2700 feet.

The additional 3300 feet required by the footprint is used to accomplish the splits. The initial two way split includes 700 feet to separate the beam into the two way Lambertsons, 1000 feet to separate the beams into two 30 mrad bends, 900 feet for the three way split to separate the beams for the three way Lambertsons, and the remaining 700 feet for the beams to drift to the position of the last four major bends.

The elements required for this configuration are given in Table 2. The most significant in terms of cost are the cryogenic bends.

Switchyard Optics for Both High and Low Energy Transport

Beam transport optics for the Switchyard cannot be completed until the vertical position of the SSC is fixed. However, a feasibility study was carried out with an early footprint configuration (now obsolete) to demonstrate the feasibility of using the same transport system for both 200 GeV and 2000 GeV beam. This study also provides an estimate of the number of quadrupoles that will be needed in the Switchyard. The conditions assumed in the study were more difficult than would be involved in the current footprint. Large dogleg bends were assumed in the vertical (55 mrad) and horizontal (37 mrad) to bring the calibration beams to the surface, and to orient the beams close to the campus area.

The beam envelope for the transport system assumed in the feasibility study is shown in figure 5A for the low energy (200 GeV) beam. The corresponding optics for the 2000 GeV transport is given in figure 5B. Both beams use the same set of magnets, although some of the quadrupoles are turned off for the high energy transport. (See Table 3.) In the figures, x represents the horizontal axis, and y the vertical.

The high energy transport is straightforward and offers no significant difficulty. The transport system for the low energy beam is much more challenging, because the vertical emittance is a factor of four larger than at the higher energy. Therefore, fewer quads are needed to tarnsport the high energy beam.

A further constraint on the beam optics comes from the geometry of the Switchyard. When beams are split, they will drift fairly close to each other for long distances. Quadrupoles cannot be placed in these areas, because they may refocus the beams - thereby canceling the effects of the split. For this reason, quadrupoles cannot be placed in some regions upstream of the Lambertson magnets.

The optics are constrained to fit the beam through the magnet pertures. The beam envelope completely fills the 1.25 inch Lambertson aperture, leaving no room for tolerances. This problem may force us to evelope a 1.5 inch Lambertson. This constraint also required an additional 530 feet in beam length to develop the proper distance between quadrupoles. This indicates that the final Switchyard configuration may have to be made a bit longer than shown in figure 4, or may have to have an extra magnet added in the cryo strings, to successfully accommodate the dynamic range needed by the transport system.

Secondary Beams; Wide Band Beams

The secondary beams are designed to deliver particles according to the specification given in Table 1. Perhaps the most stringent requirement has to do with the need to deliver 1 GeV with fluxes of about 100 Hz. It is virtually impossible to design a dynamic range of 1000 into a single beamline, so that this low energy requirement dictates the need to deliver the low energy beam of 200 GeV from the MEB and to transport these protons to a second target station for a shorter beam. The manner in which this is achieved will be described shortly.

Other driving factors in the specification are the need to achieve 10^7 particles at 100 GeV to study pileup issues, and 100 Hz of electrons at the highest possible energy. To meet these requirements in a manner that is consistent with the rest of the specification, a wide band photon beam approach was chosen. This beam at Fermilab has excellent electron yields, and can also deliver a large hadron flux as well. For the SSC design, the beam would be much longer, because 2 TeV would be incident on the target, and the test station requires that muon flux should be below $150kHz/m^2$. A length of 1640 feet was chosen which satisfies the requirement for muon shielding and still has good yields and acceptance. The schematic of the beam optics is shown in figure 6.

The way in which the requirements for high energy are integrated with the low energy requirements is seen in the figure. The high energy beam extends over the full 1640 foot length of the beam and consists mainly of four bends that form back-to-back doglegs and therefore have total cancellation of dispersion. Therefore the beam at the target station is momentum recombined in both spatial and angular dispersion. The dipole just downstream of the target acts as a sweeper magnet to produce the electron beam, or as part of an angle varying bend system for hadronic running. Its main function is to separate the secondary beam from the primary beam so that the primary can be delivered to a dump. The beam optics is very simple, consisting of only two elements. The quad triplet just downstream of the target forms a point to parallel beam that is transmitted through the dipole strings. The corresponding triplet upstream of the test station focuses the incoming parallel beam onto a spot at the test station. At some lower momentum, the quads will also transmit the full acceptance, but with an intermediate focus, as shown in figure 6. This is the source of the wide band property of the beam: That it has good acceptance at two distinct momenta.

The low energy beam will be generated from 200 GeV protons transmitted to a secondary target located about 700 feet upstream of the test station. The short beam is needed because particles of low energy (that is near 1 GeV) will decay in a long beamline leaving no flux at the test station. However, muon shielding requires that the beam energy on target not be excessive, or the test station will be swamped with muons. The beam itself is simply a short wide band beam. Similar elements are used to perform the needed functions: two sets of quad triplets to form a point to parallel to point beam; a non-dispersive dipole string to define the momentum acceptance of the beam, and a set of sweeper dipoles just downstream of the primary target to segregate the primary and secondary beamlines. The beams entering the test station are separated by 18 inches. The expected yields for both the high and low energy beams are given in Table 4.

Radiation Shielding

Shielding calculations were carried out for the high energy secondary beamline. Hadron shielding was not considered an issue because the beam was assumed to be at least thirty-three feet below grade. Muon shielding calculations were the main focus of the effort, because muons have the most significant influence on site boundary and real estate procurement issues. These calculations were carried out with the program CASIM [5] used at Fermilab. The most important beam parameters used were the target size (about one interaction length of beryllium), the extent of the sweeping magnets just downstream of the target (four 12 foot Eartly bends running at 1.8 T were assumed), and the beam configuration given in figure 6. The calculations included the effects of pion and kaon decay in the secondary beamline, and the direct production of muons in the target and beam dump. The material surrounding the beam was assumed to be composed of "Austin chalk".

The 1640 foot length of the beam was chosen from a set of muon calculations that indicated that roughly this length would be needed to keep the background muon rates below $150kHz/m^2$. This set the length for the beam optics design, which was optimized to achieve the yields called for in the specification. The final shielding calculations were then done for this beam design and the results are presented here.

Figures 7A and 7B show the horizontal and vertical distribution of muons at the test hall at $z = 1640$ feet for various settings of the (horizontal) sweeper magnets. The widest distribution results when the sweepers are operating at full field, as they would when the beam transmits high energy electrons. The effective width (full width at base) of the muon distribution for this case is about 75 feet. This width determines the distance required between test stations at the test beam hall if each beam is to operate independently of the

[5] A. Van Ginneken, P. Yurista, and C. Yamaguchi, *Shielding Calculations for a Multi-TeV Collider*, Fermilab Note FN447 (Jan,1987)

others without interference from ambient muons. Because we can anticipate that a great deal of personnel entry will be required at the test stations, it will be very important for the adjacent beams to operate regardless of the activity in a neighboring beam. The distance between test stations was therefore chosen to be 75 feet, and this should meet the requirements for independent operation.

Table 5 gives the results of the muon shielding calculations in numerical form. Column B gives the average flux per cm^2 per incident proton within a two meter radius. Column C gives the flux density in Hz/m^2 with 10^{12} protons on target per 40 sec spill. Column D gives the dose rate in mrem for a run of 10^{18} protons. The site boundary limits are given at 3280 feet where the exposure is about 0.1 mrem for a run of 10^{18} protons. An additional 1640 feet will be required to allow for the possibility of delivering machine energy protons directly to the Calibration Beam Hall.

The muon rates at the test stations are given by the entries at 1640 feet in the table. This rate is highest when the beam is running for low energy electrons and is about 152 kHz/m^2 with 10^{12} protons on target per spill. This is essentially within the specification.

Tagging System

Momentum tagging to 0.05% dP/P may be accomplished with four detectors situated before and after one of the 3 mrad bends just before the detector halls. If 20 micron resolution silicon strip detectors are used, the detectors may be only 100 feet apart. This solution requires many channels of electronics, but needs little maintenance and calibration. For a detector size of 4 inches, 2000 channels of readout electronics are required per plane. Depending on momentum tagging requirements at high rates, the number of channels could be reduced by reading out every N strips and interpolating using charge division. Standard drift chambers of 150 micron resolution could be considered, but the detector spacing must increase to 600 feet. A drift chamber solution would also impose a rate limit of $\sim 1 - 3Mhz$, and would require more computing overhead for calibration.

Particle identification at the 99.9% confidence level is very difficult to achieve at energies above 100 GeV. At lower energies, multiple conventional threshold Cherenkov counters can achieve the required identification of all species. Two candidates for particle identification at higher energies are transition radiation detectors (or TRD's) and synchrotron radiation detectors.

A TRD module is usually constructed of many thin lithium or polypropylene foils followed by a standard PWC. Successful operation depends on low Z foil materials, and high Z PWC gas. A mixture of Xenon-methane is usually used for gas. TRD's can provide an additional tag for electrons at the 99% level and with 90% efficiency for energies below 100 GeV. The same TRD identifies muons above 50 GeV and kaons and protons above several hundred GeV.

Identification of electrons at energies above 100 GeV should be possible using synchrotron radiation from the 3 mrad bends. A 1.5 TeV electron bending 3 mrad through 60 feet of magnet will emit roughly fifty 1.1 GeV photons. The photons are emitted in a narrow stripe of angle 3 mrad in the bend plane and $1/\gamma$ in the transverse plane. The 4% energy loss makes particle identification easy at high energy, but momentum tagging difficult. At 100 GeV, however, only four 1 MeV photons are emitted from the 3 mrad bend. A high field dipole should be considered for electron identification in this energy regime. Estimating the confidence level and identification efficiency is highly dependent on the beam quality and requires a careful study.

It is apparent from the above discussion that there is no clear cut approach to achieving the 99.9% confidence level for identification of pions, kaons and protons above 100 GeV. It may be possible to improve the confidence level somewhat with severe cuts on TRD signal pulse heights, but the tagging efficiency may be unacceptable.

Test and Calibration Halls

To understand what scale of facilities are needed for calibration halls, a few prototype experiments were chosen and calibration stands were designed for the major components of these detectors. The detectors chosen are the Large Solenoid Detector (LSD) and the Bottom Collider Detector (BCD), as described in the Berkeley Workshop [6]. The LSD is a "4π" detector with a large central tracking chamber, and calorimeter inside a large solenoidal magnet. The flux return yoke is used to both trigger on and identify muons.

[6] G.G.Hanson et al, *Report of the Large Solenoid Detector Group* and K.J.Foley et al, *Report of the Intermediate-$p_\perp$ Detector Group: A Beauty Spectrometer for the SSC*, Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider; Berkeley, California, 1987; Rene Donaldson and M.G.D. Gilchriese, editors.

The LSD is the largest of the proposed detectors. It is expected to identify and measure electrons, muons, and jets. The detector is designed to be sufficiently hermetic to enable an accurate measure of the missing transverse energy of the event. The BCD is one of a class of possible SSC detectors with relatively moderate dimensions transverse to the beamline but much longer along the beamline than the LSD. The BCD is expected to identify and measure electrons and muons and to accurately track all charged particles outside of the beam regions. Possible versions of these detectors are shown in figures 8A and 8B.

The general requirements of the test stands are that they move to cover the full range of particle angles that particular type of detector might see in the actual experiment. Further the stands should retract from the beam line while not being tested so that components in downstream positions may be tested. The design should allow movement of the individual components to a position outside the radiation fence so that when access to the hall is possible work can be done on these components.

For the LSD the principal calorimeter is assumed to be liquid argon. Because of the need for a cryostat and a large volume of liquid, this calorimeter is deliberately thin and in some designs is followed by a second coarse grained calorimeter whose type has not been defined. This second calorimeter, called a "tail catcher", is assumed to have less resolution and to use a simpler technology. The calorimetry was inside a large solenoidal magnet. Outside the magnet coil muon tracking chambers remeasure the momentum of the muon as it traverses the return yoke of the magnet.

The argon calorimeters have no intrinsic electronics gain, so that not every module need be in the test beams. To calibrate the energy response over the entire detector there must be a sufficient portion of the calorimeter available to test so that every possible trajectory of particle that could be produced in the experiment can be simulated in the test beam. For this purpose a cryostat was designed that would have two insertions, one containing a portion of the endcap calorimeter and one a portion of the barrel calorimeter. The cryostat is mounted on a table which has sufficient degrees of motion to allow the beam to go directly down each tower in the calorimeter. An elevation view of the calibration beam line for the LSD is shown in figure 9 and the plan view of the entire calibration hall is shown in figure 10.

To calibrate the forward calorimeter requires a smaller range of motion so it can be mounted on rails with jacks to give the correct vertical position. The forward calorimeter is placed so it and the endcap test module can have the correct orientation to study the transition between the central and forward calorimeter.

The test stand for the tail catcher calorimeters is sufficient to allow each of the towers to be aligned with the beam. Exactly how much calibration will have to be done on this calorimeter will depend on the technology chosen. The test stands for both the forward and tail catcher calorimeter are designed to move sufficiently out of the beam path so that it would be possible to work on them when there is low flux running in the collision hall.

A muon chamber stand is located behind a block of iron so that energy losses by high energy muons are properly simulated. The chamber is mounted on rails so that one can scan the entire length of the chamber. It can also be rotated so the particles traverse the chamber at the correct angle.

One stand has been added for tracking chambers. This stand can be used as a general purpose setup for whatever additional test beam needs arise.

A different approach to collider experiments is made by the BCD experiment. Here the interest is in measuring $B - \overline{B}$ production and decay. These events generally have low transverse momentum and interesting events occur close to the beamline. This is an example of a non 4π, special purpose experiment with very stringent requirements on tracking and particle identification. This experiment provides a nice contrast with general purpose experiments such as the LSD in understanding the utility of the calibration halls.

The BCD is designed to detect the decay products of bottom particles, thus it must have good momentum measurement of both high and low momentum tracks. Since one of the bottom particles may decay semileptonically, this experiment needs very good lepton identification, even in the presence of substantial backgrounds. From figure 8B we see that the experiment is based on a large volume magnetic field. In the magnet and along the beam line a large number of different types of detectors are needed to sufficiently identify the events of interest.

The various components of the experiment were placed along the calibration beam line. The order in which the test stands were placed was the same as that in the experiment although this was not judged to be essential. Angle sensitive devices such as the RICH counter are on stands that permit the particles to go through the detector with all the possible trajectories of the experiment. After the RICH and TRD detectors, additional electron identification is provided by a lead glass (or BGO) shower counter and a small hadron calorimeter used in veto mode. The electromagnetic calorimeter is on a turntable which can accommodate either the large angle or small angle calorimeters. The muon chambers have magnetized steel both in front and back to simulate the environment expected in the actual experiment.

As with the LSD calibration beam each of the detectors can either be lowered or moved out of the beam line so that the following detectors can have unobstructed beam particles coming into them. In each of the beam halls it is envisioned that there will be a low intensity mode of operation so that work on detectors or electronics can take place outside a radiation fence. Since each beam is outside the muon flux envelope of the other beams, they can all be operated completely independently of the other beams.

Conclusions and Further Work

We believe that the ideas presented here form a viable basis for the calibration beams at the SSC. There is clearly much work to be done before this can be considered a complete design. There needs to be detailed design and engineering on all of the components presented here. In particular the the beam line optics has not been done in detail, the civil engineering for the tunnels and beam enclosures has not been done, and the engineering design for the detector halls has not been done.

One issue in particular that needs further study is the particle identification for these beams. We do not have a way of measuring electron momenta well enough to be able to calibrate electromagnetic calorimeters at their expected resolution.

A design for switchyard optics for the final beam configuration must be completed. This will be done after the vertical profile for the SSC is fixed.

The development of the ideas presented here is ongoing. We expect to develop a conceptual design for calibration beams for the SSCL. We encourage those members of the High Energy Physics community that have opinions on the ideas presented here or additional thoughts relating to calibration beams to contact one or more of the authors of this document and express those opinions.

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Table 1

Specifications for the SSC Test/Calibration Beams

A Lepton ID

1. Beams to Highest Possible Energy at 100 Hz. of e, μ, π

2. Particle ID 1000:1

3. Energy Resolution
   absolute 1/3%
   relative 0.05%

B Hadron response

1. Beams in 1 to 100 GeV range

2. Flux up to 10^7 per sec but rarely

3. Particle ID 100:1

C Muon Flux at Detector Hall <150kHz/m^2

D 2 TeV @ 10^7/sec

Table 2

Switchyard Component List

Electrostatic Septa	30
2-Way Lambertsons	6
3-Way Lambertsons	12
4 T Tevatron Dipoles	66[a]
3Q120 Quadrupoles	141[b]

Table 3

Estimate of Quadrupole Requirements for the Switchyard Transport Based on a Feasibility Study

Name	Position (feet)	Field (Kgauss/in)		3Q120	
		200GeV	2000GeV	#magnets	#beams
Q1	-3723	-0.40	off	1	1
Q3	-2840	-0.76	-4.13	2	
Q4	-2809	0.82	3.43	2	
Q5	-1958	-2.90	-0.91	1	
Q6	-1948	3.20	2.53	1	
Q7	-681	-1.46	1.55	2	2
Q8	-650	1.55	2.75	2	
Q0	-393	-2.05	off	1	
Q9	-25	-2.70	off	1	
Q10	-6	2.70	off	1	
Q11	1588	-0.60	-4.39	3	6
Q12	1630	0.60	4.29	3	
Q11B	2089	-3.04	off	1	
Q12B	2100	1.76	off	1	
Q13	3633	-0.89	-2.55	2	
Q14	3664	0.98	3.90	2	
Q15	4290	0.59	-3.93	4	
Q16	4344	-0.49	3.99	4	
					Total = 141

[a] May change when the final vertical profile of the SSC is fixed.
[b] Based on feasibility study. Will change when final vertical profile of SSC is fixed.

Table 4

Particle Yields for High and Low Energy Beams

PROTON ENERGY	P GeV/c	PI minus	e(sweep)	e(natural)
2000	1500	5 E-6	1 E-8	
2000	500	3 E-3	3 E-4	
2000	100	8 E-4	1 E-3	
2000	50	2 E-4	1 E-3	
200	50	2 E-5	4 E-6	
200	10	5 E-6		30% (est)
200	2	7 E-8		40% (est)
200	1	2 E-9		50% (est)

Table 5

Muon Flux densities

Z (meters)	Ave Flux/cm^2 per inc. R < 2 m	Hz/m^2 @ 1 E12/pulse	Mrem/ 1E18 inc
100 GeV Transport:			
100	5.91 E-08	1.48 E +07	2.36 E+06
300	3.39 E-08	8.48 E +06	1.36 E+06
500	6.09 E-10	1.52 E+05	2.44 E+04
700	1.18 E-10	2.95 E+04	4.72 E+03
900	9.74 E-12	2.44 E+03	3.90 E+02
1100	1.22 E-12	3.05 E+02	4.90 E+01
1300	4.19 E-14	1.05 E+01	1.68 E+00
750 GeV Transport:			
100	2.79 E-08	6.98 E+06	1.12 E+06
300	1.88 E-09	4.70 E+05	7.52 E+04
500	4.42 E-10	1.11 E+05	1.77 E+04
700	1.17 E-10	2.93 E+04	4.68 E+03
900	3.56 E-11	8.90 E+03	1.42 E+03
1100	6.94 E-12	1.74 E+03	2.78 E+02
1300	2.15 E-12	5.38 E+02	8.58 E+01
1500	2.69 E-15	6.73 E-01	1.08 E-01
1500 GeV Transport:			
100	5.25 E-08	1.31 E+07	2.10 E+06
300	4.65 E-10	1.16 E+05	1.86 E+04
500	7.55 E-11	1.89 E+04	3.02 E+03
700	1.54 E-11	3.85 E+03	6.16 E+02
900	1.69 E-12	4.23 E+02	6.76 E+01
1100	2.56 E-13	6.40 E+01	1.02 E+01
1300	1.82 E-14	4.55 E+00	7.28 E-01

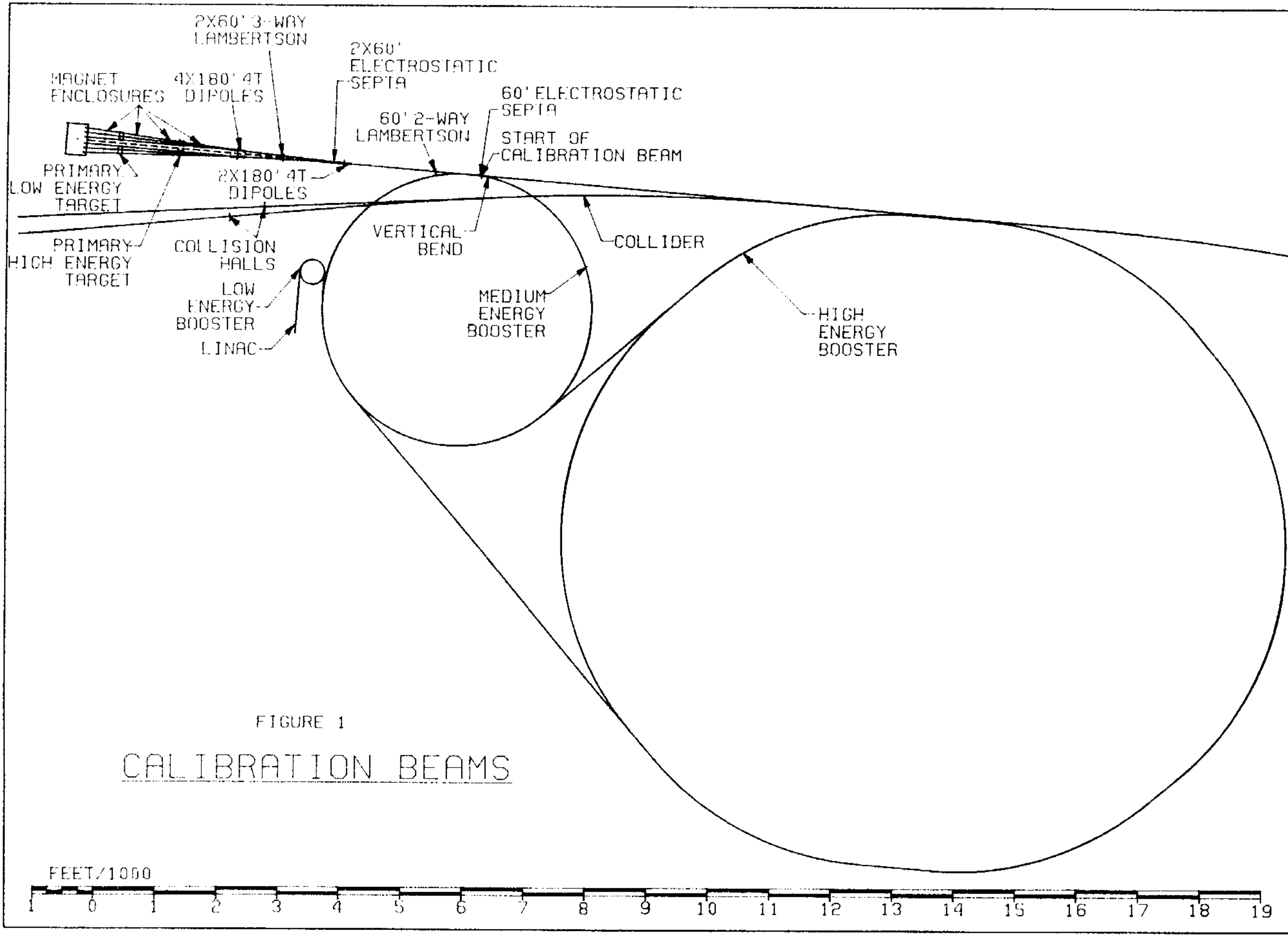


FIGURE 1

CALIBRATION BEAMS

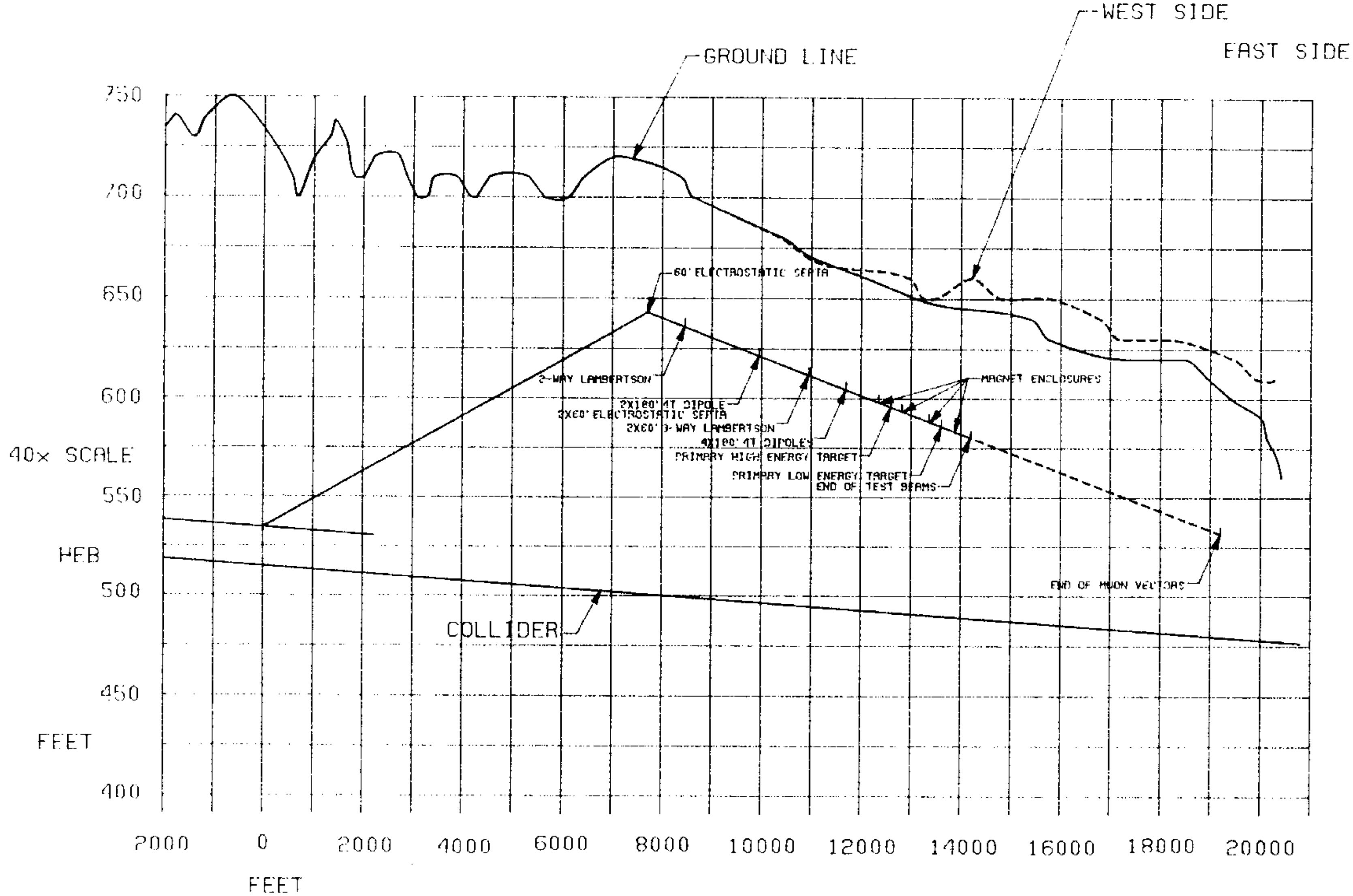


FIGURE 2

CALIBRATION BEAMS - PROFILE

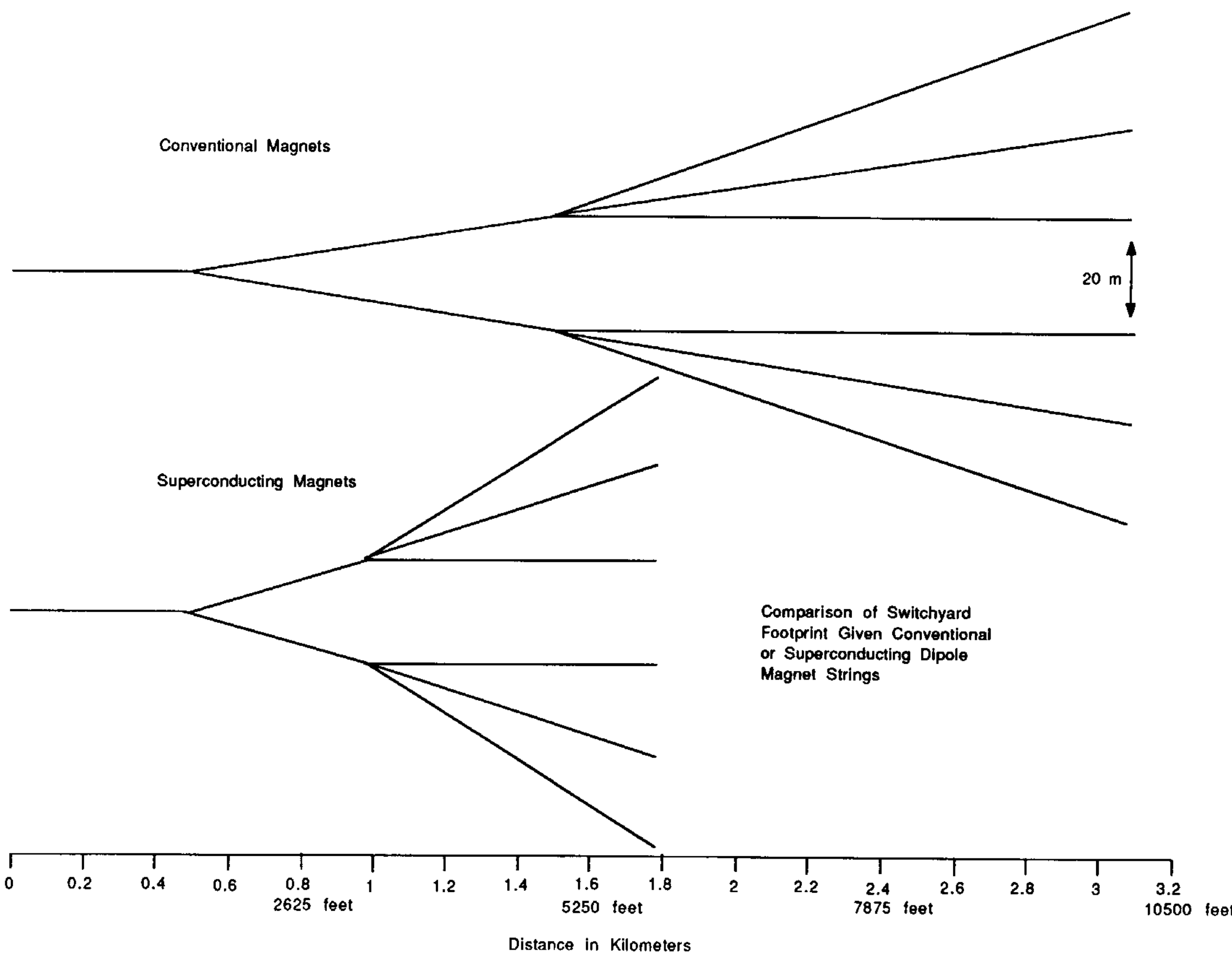

Conventional Magnets
20 m
Superconducting Magnets
Comparison of Switchyard Footprint Given Conventional or Superconducting Dipole Magnet Strings
0
0.2
0.4
0.6
0.8
2625 feet
1
1.2
1.4
1.6
5250 feet
1.8
2
2.2
2.4
7875 feet
2.6
2.8
3
3.2
10500 feet
Distance in Kilometers

Figure 3

CALIBRATION BEAM SWITCHYARD

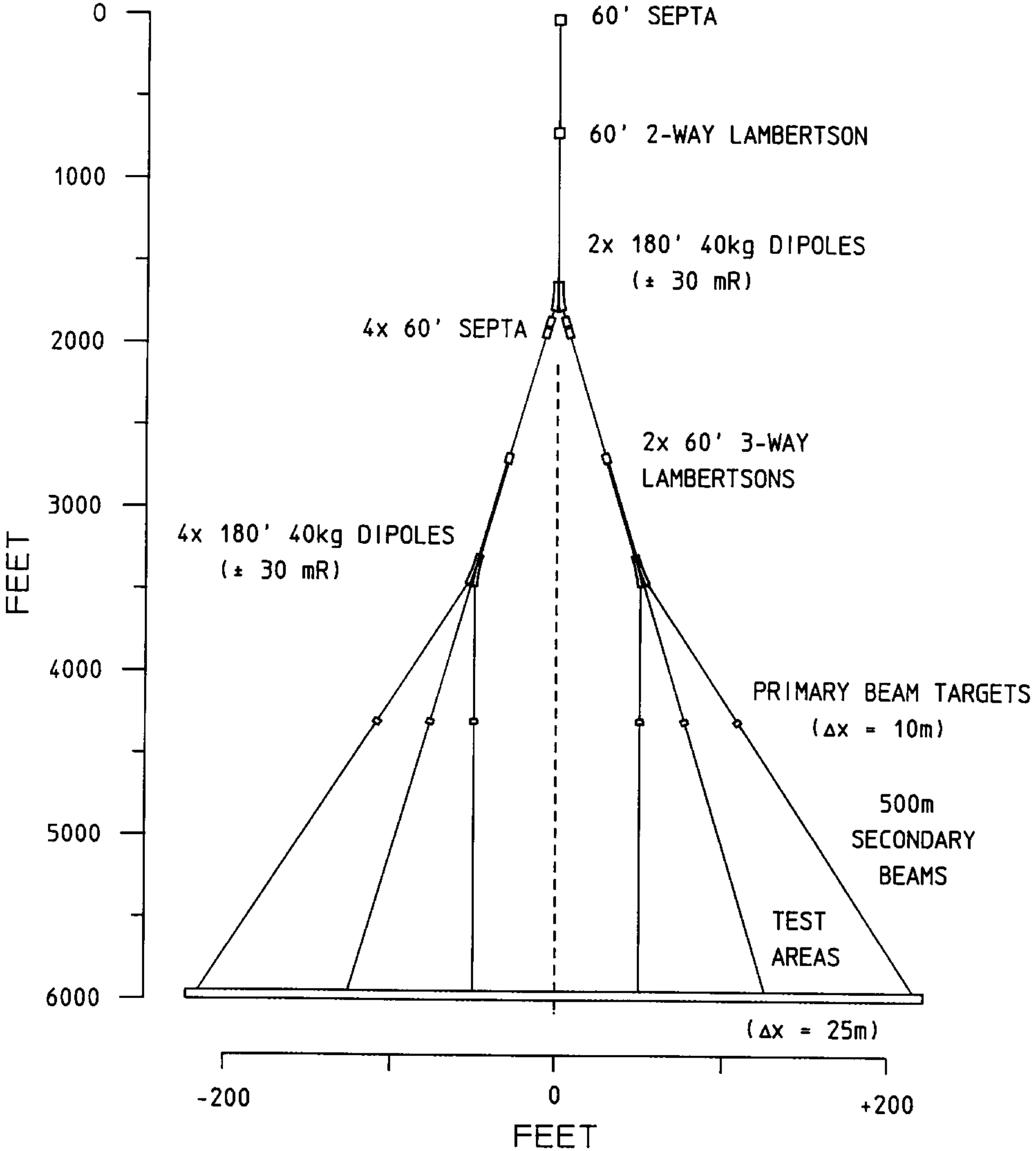
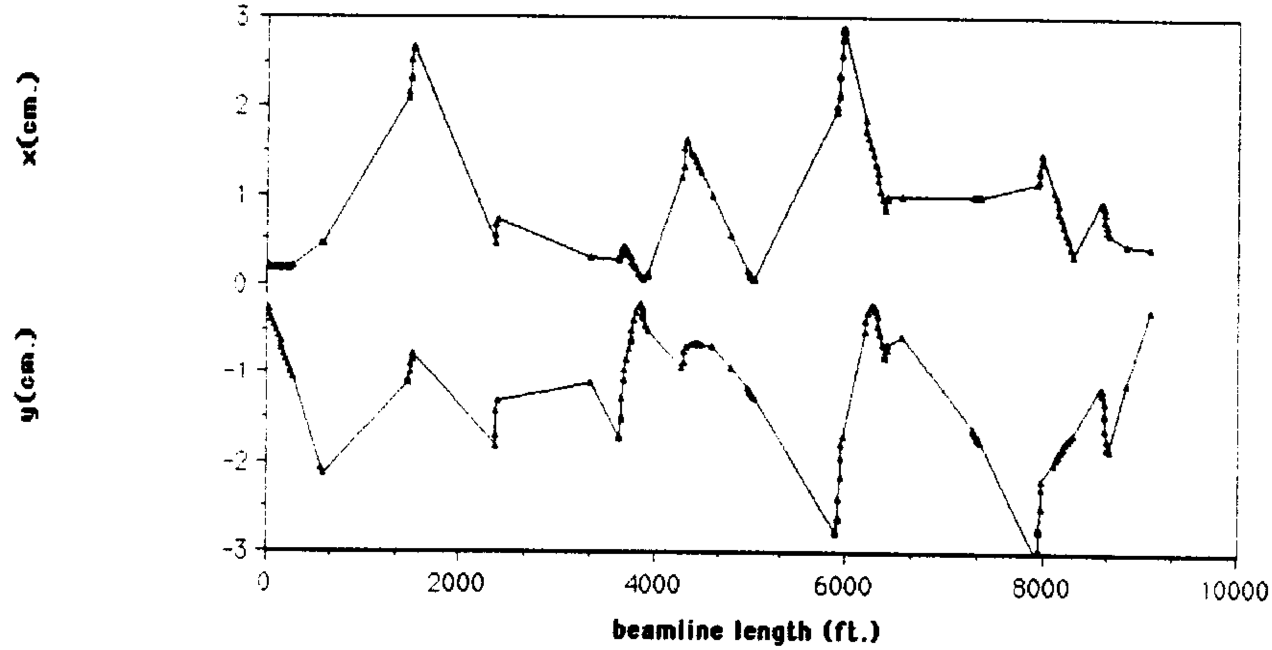


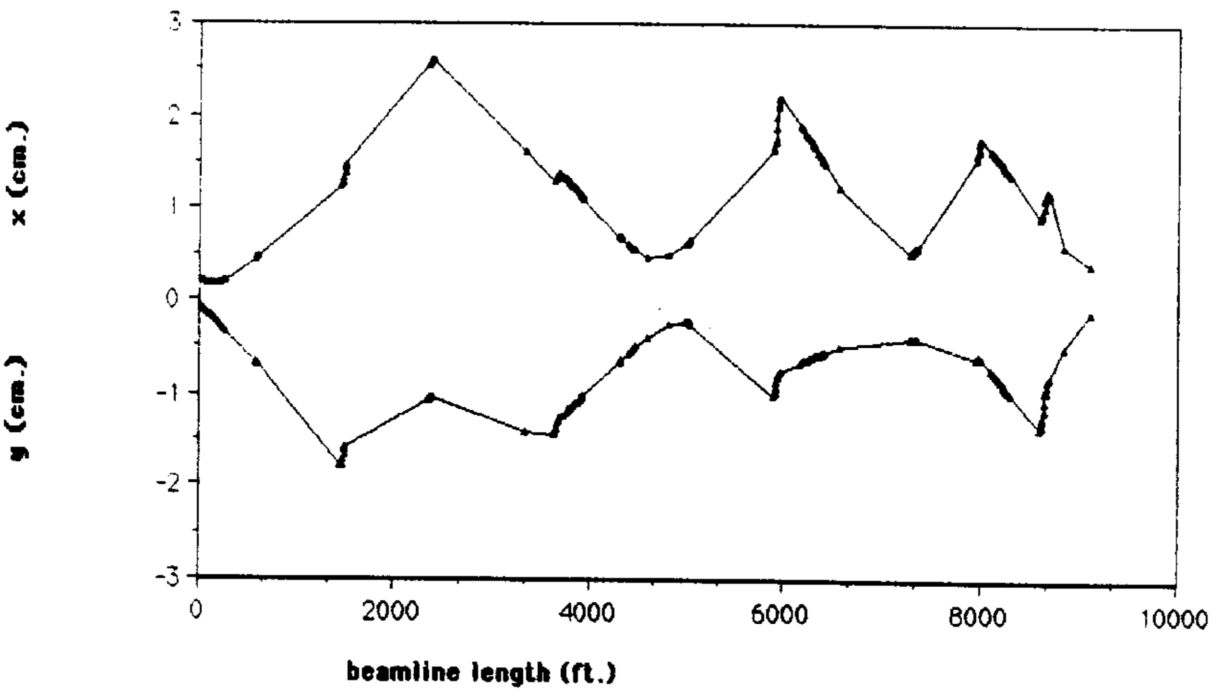
Figure 4

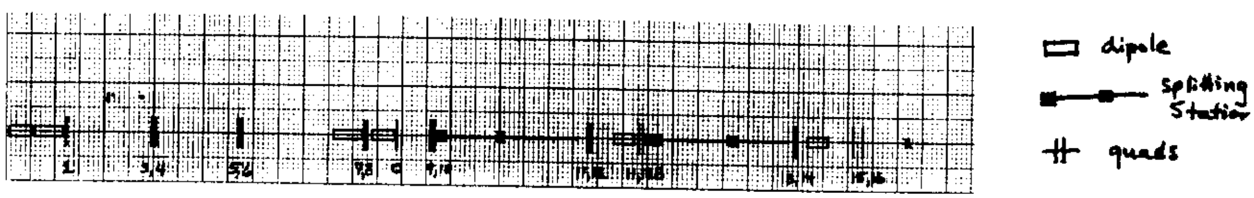
JBENSGR_cal_tb_swthyd
BENSINGER/CHAN 21jun89

200 Gev Beam half-width at base (98%) Figure 5A



2000 Gev Beam half-width at base (98%) Figure 5B





Schematic Drawing of Wide Band Beam Optics

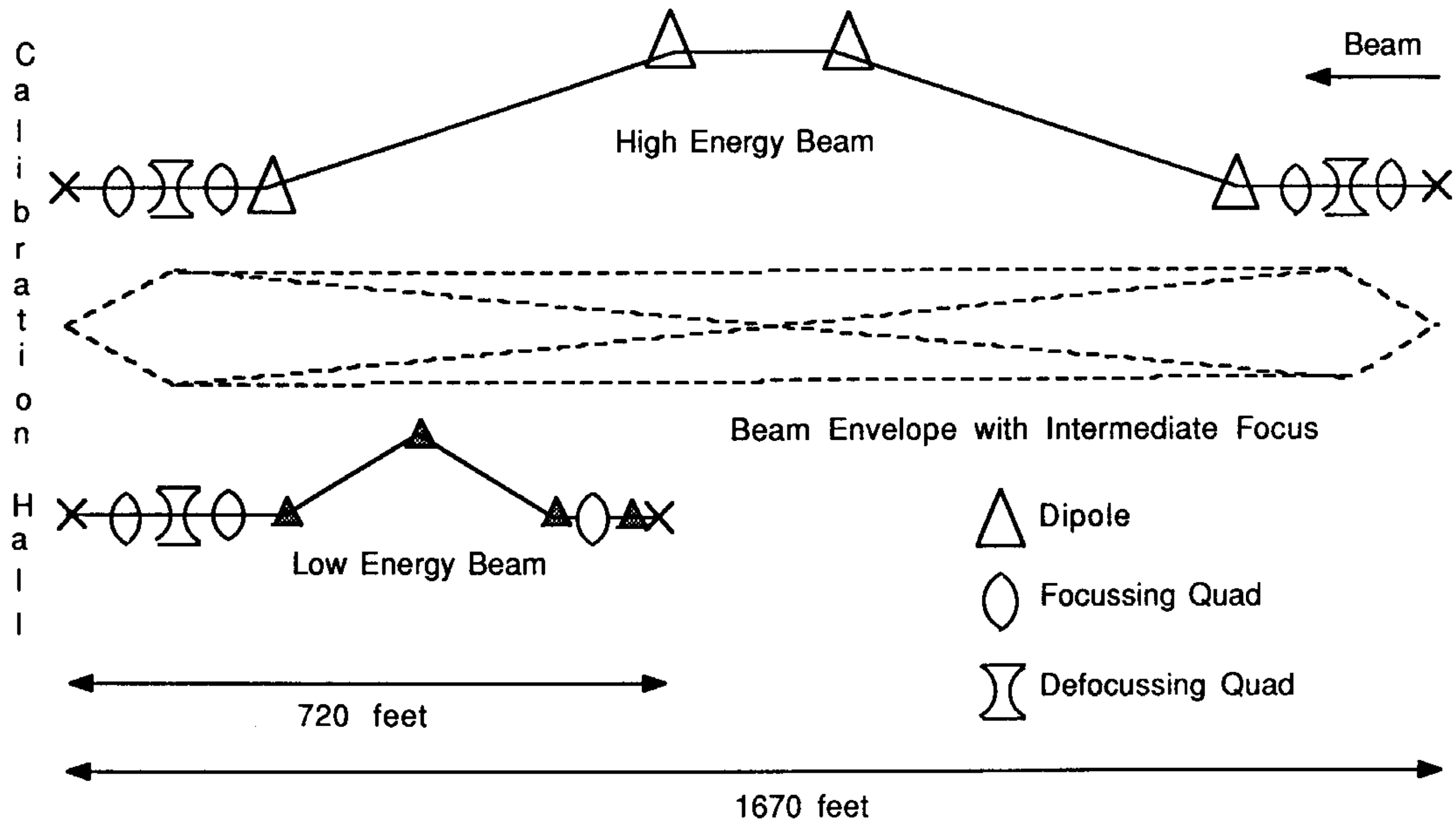


Fig. 6

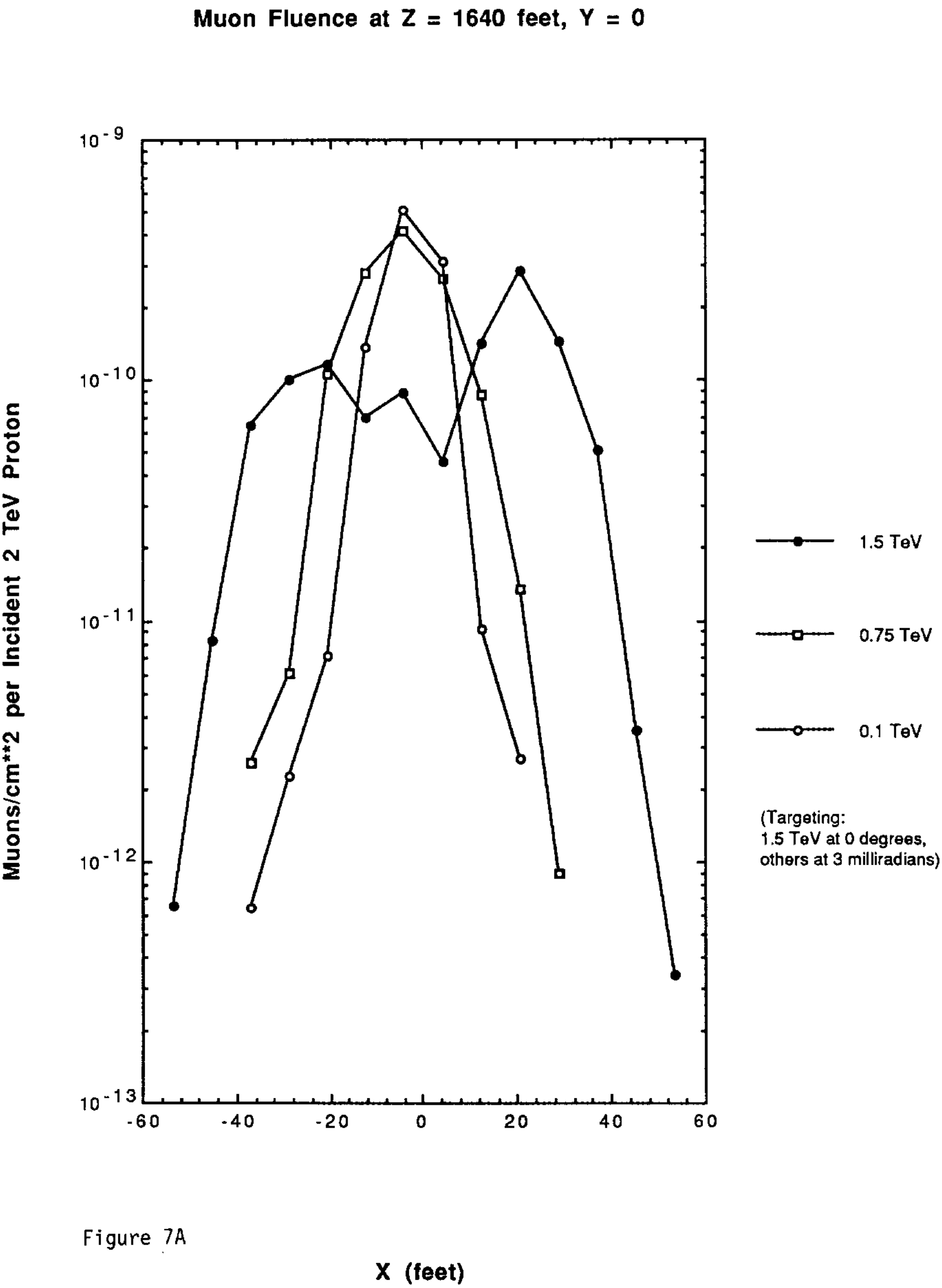

Muon Fluence at Z = 1640 feet, Y = 0
Muons/cm**2 per Incident 2 TeV Proton
10^-9
10^-10
10^-11
10^-12
10^-13
-60
-40
-20
0
20
40
60
1.5 TeV
0.75 TeV
0.1 TeV
(Targeting:
1.5 TeV at 0 degrees,
others at 3 milliradians)
X (feet)

Figure 7A

Muon Fluence at Z = 1640 feet, X = 0

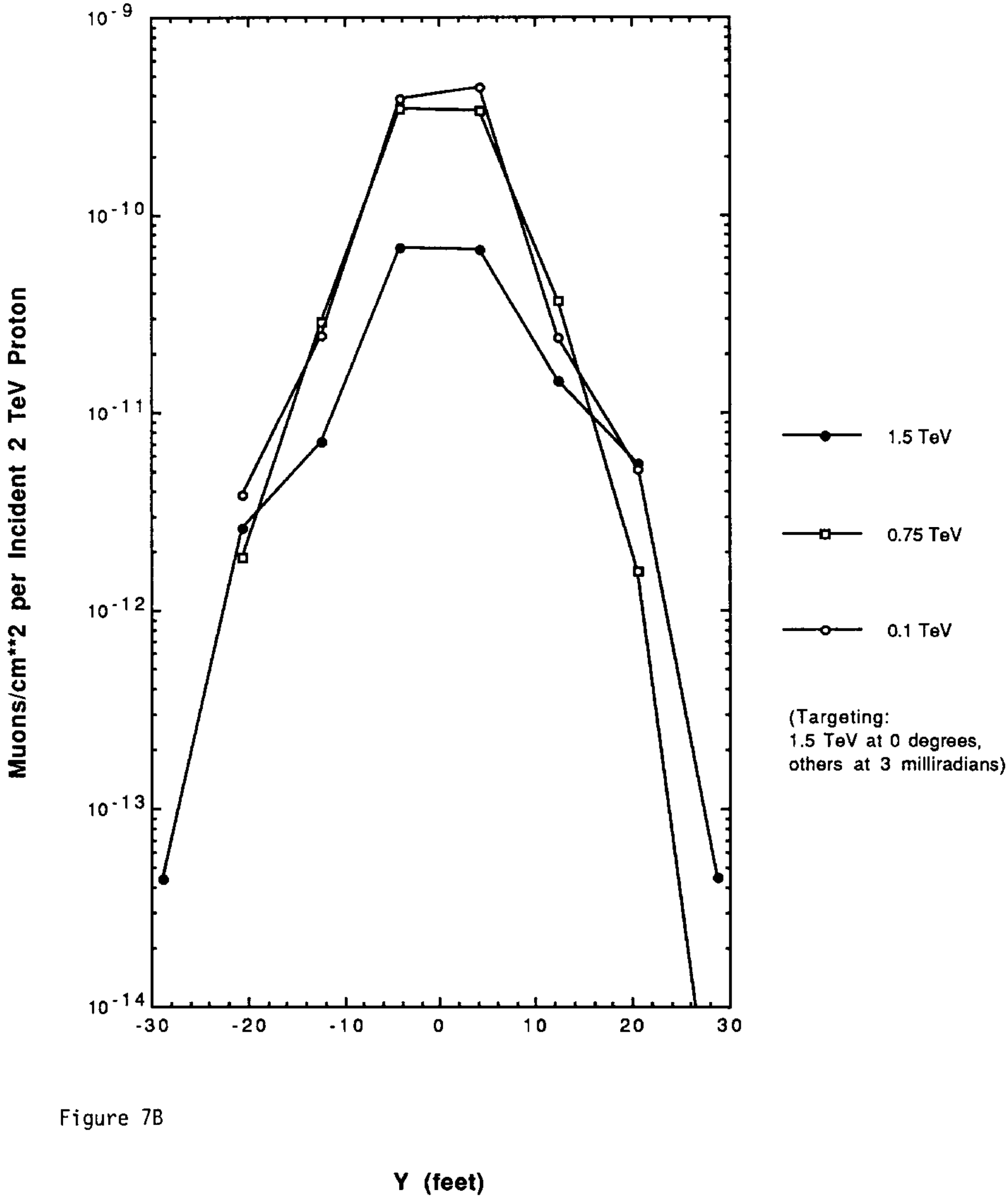
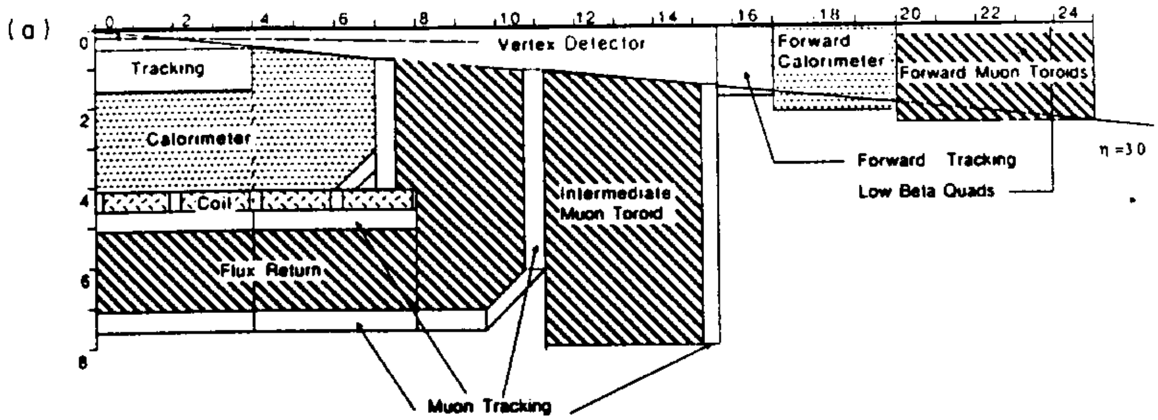
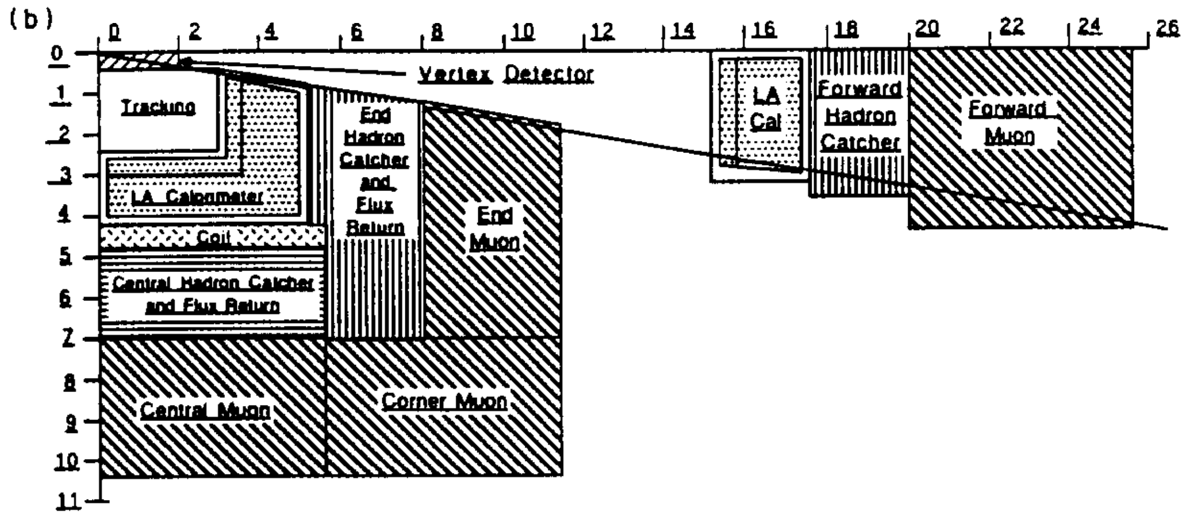


Figure 7B

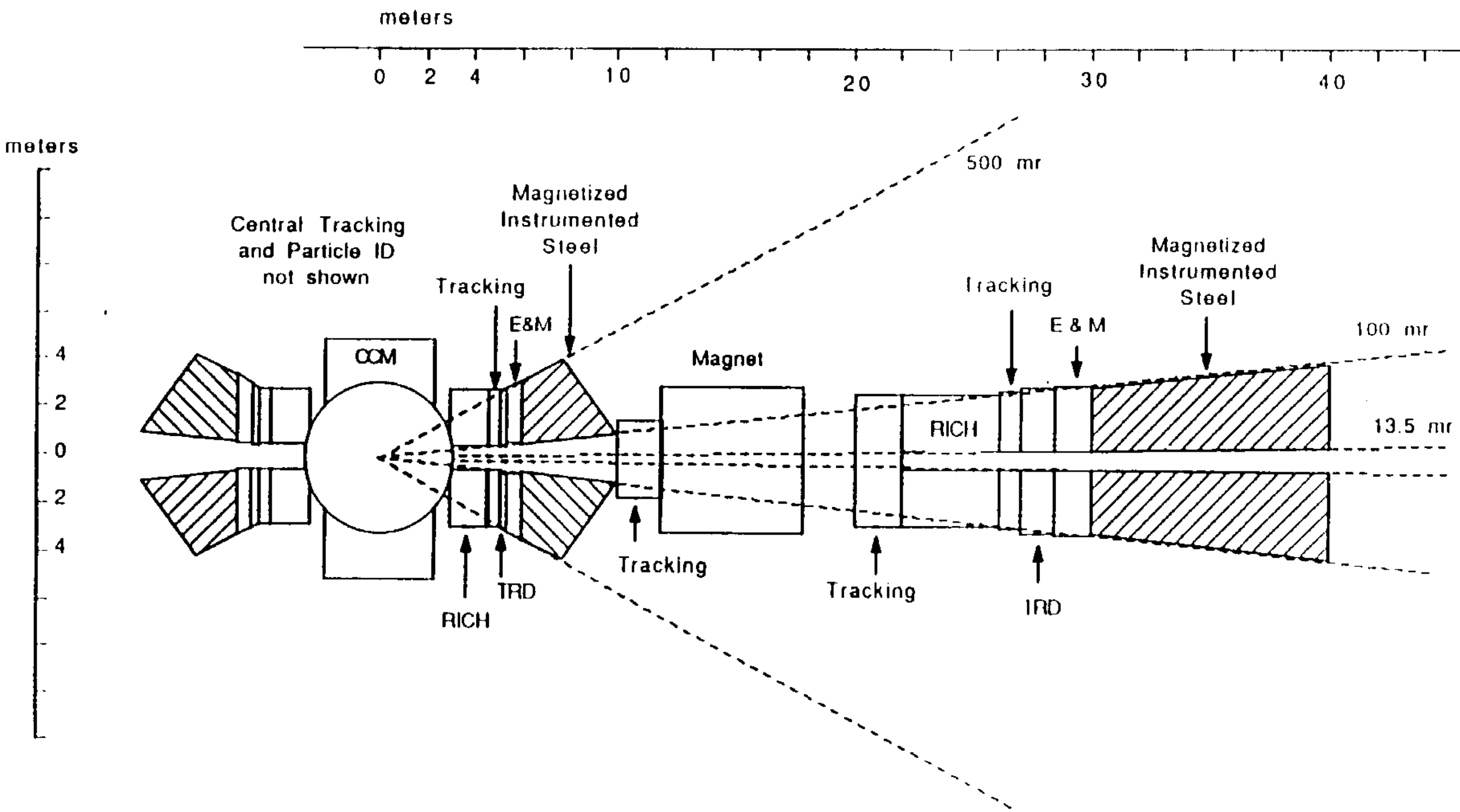


(a)
Vertex Detector
Tracking
Calorimeter
Coil
Flux Return
Intermediate Muon Toroid
Forward Calorimeter
Forward Muon Toroids
Forward Tracking
Low Beta Quads
η =3.0
Muon Tracking



(b)
Vertex Detector
Tracking
LA Calorimeter
Coil
Central Hadron Catcher and Flux Return
End Hadron Catcher and Flux Return
End Muon
Central Muon
Corner Muon
LA Cal
Forward Hadron Catcher
Forward Muon

Figure 8A



SSC BEAUTY SPECTROMETER
(Snowmass '88)

Figure 8B

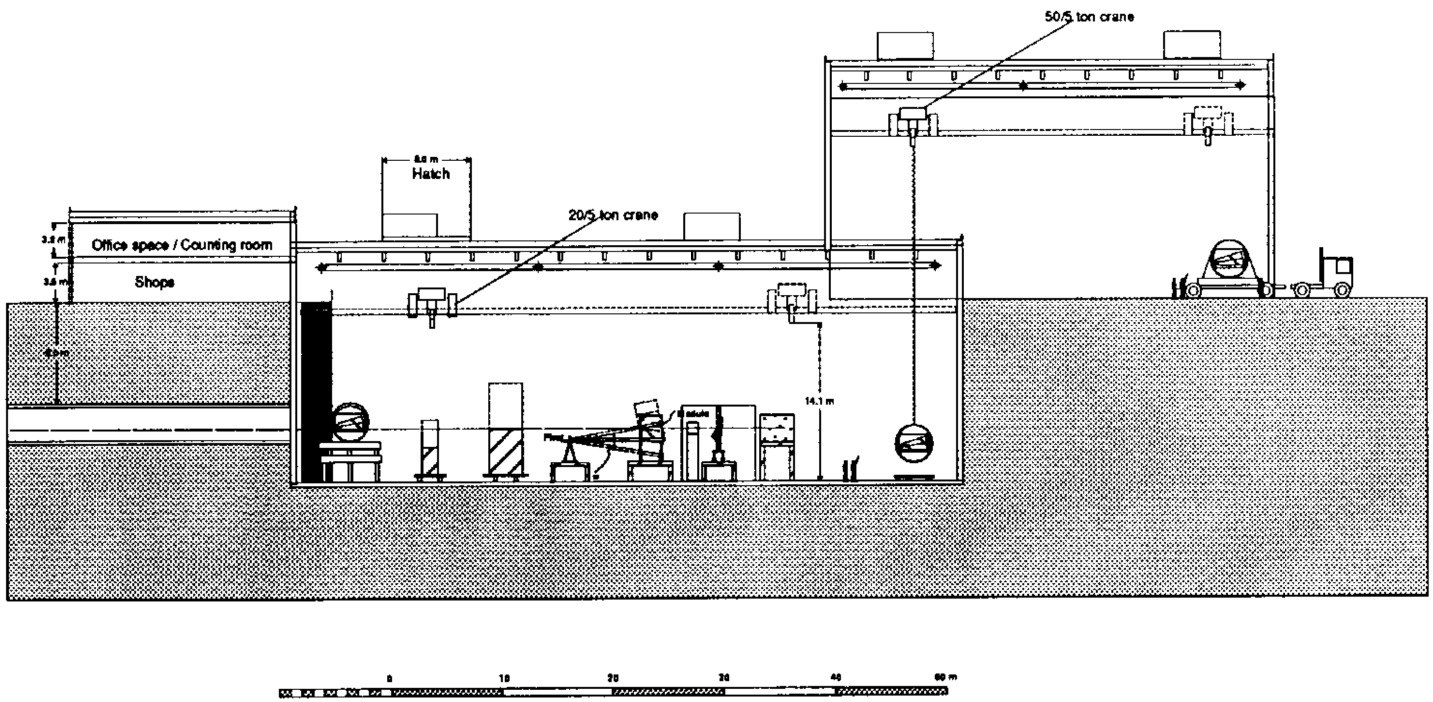


Figure 9

Test beam facility, LSD line Side view A.Autin 6/89

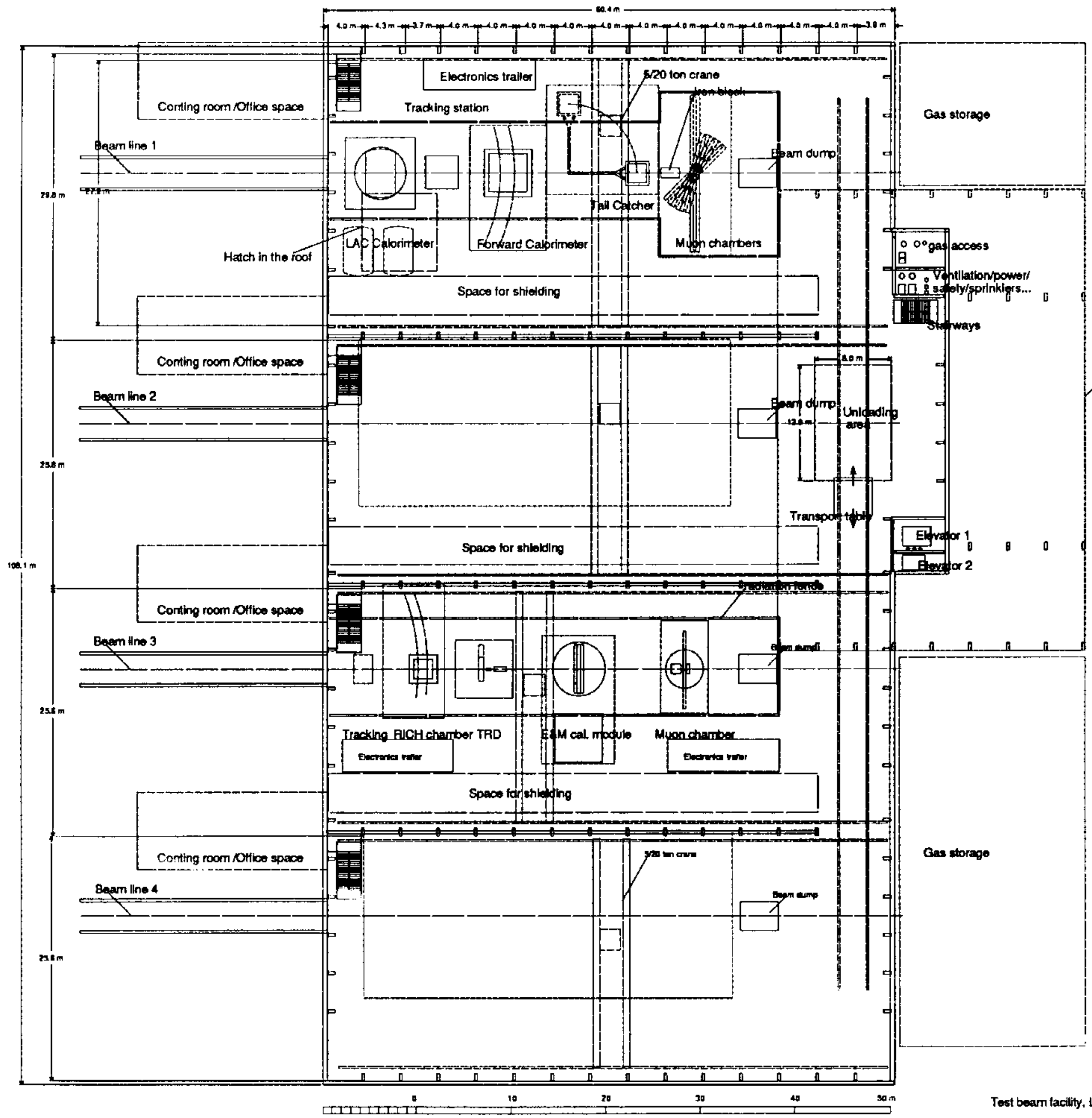


Figure 10

Test beam facility, LSD line Plan view A.Autin 6/89